SUrface Mass balance and snow on sea ice working groUP (SUMup) Discussion Notes

Compiled by Lora Koenig, Rick Forster, Jason Box and Nathan Kurtz

This document contains the bullet point meeting notes from the discussion session at the SUMup inaugural meeting on September 20-21, 2012 at Goddard Space Flight Center. The discussion was directed at answering the larger question: How is ice sheet surface mass balance and snow on sea ice important? Discussion led to the following 8 questions and approaches for answering the questions. The list of approaches in this document encompasses all discussion had at the meeting and is not in any priority order.

SUMup Key Science Questions:

1) What is the mass balance of ice sheets and how do we quantify and reduce uncertainty in mass balance estimates by constraining surface mass balance (SMB)?

Importance: Understanding the past and current mass balance of the ice sheets is necessary for determining present and future sea level contributions. Accumulation is the largest single component of surface mass balance and the only mass input to ice sheets. Therefore, understanding the uncertainty of accumulation is needed to assess and improve meteorological and climate models and to improve sea level rise estimates.

- Develop decades long standardized data time series and spatial data (grids) of SMB components over both ice sheets including accumulation data from:
    - **Observations** utilizing ice cores, stake lines, near surface radars, AWS station data and precipitation and blowing snow measurements. Develop new methods for measuring precipitation and blowing snow which may utilize towers, kites or balloon or other technologies. Precipitation, which is the single most important positive term in the surface mass balance equation, is barely known over much of the region of interest.
    - **Models** using fields of precipitation and evaporation including sublimation. The models should be run over both the ice sheet and sea ice domain.
    - **Remote sensing** using multiple sensors including passive and active microwave, GRACE, ICESat, ICESat-2, Cryosat2, WindSat, CloudSat, etc, for both the net surface mass balance ant it's various components, including precipitation, melting, blowing snow, etc.
- Compare reanalysis and regional atmospheric model data with observations and remote sensing retrievals.
- Quantify melt water production over Greenland. Utilizing the passive microwave melt area and develop new methods for deriving air to snow heat flux when air temperatures are above freezing and the ice surface temperatures from infrared remote sensing retrievals have variability capped at 0°C due to latent heat.
- Develop models of total SMB including precipitation, evaporation, sublimation, blowing snow and all of the components of ablation including melt, surface runoff, englacial runoff, retention and englacial storage. Inter-compare and determine the magnitude effects of land surface models in relation to melt water production and storage.

2) How much liquid water is produced on and contained in the ice sheets? What are the pathways for water once it leaves the surface of the ice sheet?

> *Importance: We are in a time of transition of losing the dry snow area on the Greenland ice sheet which will alter the surface processes. Warming in the Arctic means more melt water over a larger portion of the Greenland ice sheet, therefore, becoming a larger contribution to SMB. Water retention in and on the Greenland ice sheet is currently one of the largest unknowns in SMB.*

- Quantify englacial and supraglacial (lakes and streams) water. Establish estimates on the fraction of water that runs off the surface of the ice sheet, fraction that is retained in the firn through percolation as water or refreezing ice features, fraction that is stored in lakes, and the fraction that drains to the base of the ice sheet. Remote sensing (airborne and spaceborne) and field studies should be utilized.
- Determine the spatial distribution of surface runoff over the Greenland ice sheet. Use high resolution optical imagery to map supraglacial stream networks. Specifically determine where most surface water is exiting the ice sheets and incorporate water routing schemes into SMB estimates.
- Determine englacial flow system properties and processes critical to SMB and dynamics. Specifically determine a maximum spatial density of moulins within a basin for englacial routing models to incorporate.
- Determine the surface fraction of water on a basin scale for the Greenland ice sheet to enable better modeling of albedo.
- Quantify components of water sediment and nutrient flux on the Greenland ice sheet at basin scales including surface runoff, englacial storage, and basal runoff from the margins.

3) What are the impacts of freshening in the ocean from ice sheet runoff including both water runoff and blowing snow?

> *Importance: Ocean salinity is a factor in ocean circulation, temperature and sea ice production.*

- Monitor ocean salinity utilizing SMOS and Aquarius data around the ice sheets. Specific regions of interest for studying ocean freshening processes include Baffin Bay, the North Atlantic, and Pine Island Bay.
- Determine flux of freshwater at fjord terminating glaciers to improve temperature profiles in warm water fjords which feedback and influence ice dynamics.
- Studies utilizing airborne and satellite observations of supraglacial hydrology and surface velocity along with field campaigns to monitor glacier hydraulics should be implemented to quantify all sources for freshening from the ice sheets.

4) What is the relationship between surface mass balance and ice flow dynamics?

Importance: Ice dynamics, or ice flow, has incredible potential for rapidly increasing the rate at which ice is transferred to the ocean causing sea level rise. It is therefore important to assess how the mass balance of ice sheets reacts to errors or variations in SMB time series, and what feedback mechanisms are at play between atmospheric circulation, surface processes and ice sheet dynamics.

- Use ice sheet model sensitivity studies to understand the relationship between SMB and ice flow and assess the resolution at which SMB models and observations are needed to correctly constrain ice sheet flow models. Focus on the effects of both accumulation and melt water in the accumulation area, ablation area, dynamic areas, and ice shelves where understanding the runoff component of SMB is important for hydrofracture.
- Quantify errors in projections of Greenland and Antarctica's mass balance due to errors in time series of SMB used to spin-up ice flow models. Assess local effects on overall mass balance and understand which areas need to be most improved upon.
- Quantify time resolution needed in SMB time series (day vs months vs years) to correctly constrain transient ice flow models.
- Assess time scales over which feedback mechanisms between ice flow, SMB and Atmospheric Circulation become physically relevant. Quantify impact of such feedback mechanisms on ice sheet dynamics.

5) What are the impacts of blowing snow on surface mass balance, especially in Antarctica, and how does the snow blowing off of Antarctica affect the sea ice and/or freshening of the ocean?

Importance: Wind scour and redistribution of snow is a major surface mass balance component in many areas of Antarctica. Blowing snow, enhanced sublimation, and loss of snow in sea ice leads determine the mass balance of snow on sea ice, particularly for the Southern Ocean.

- Determine the magnitude of mass transport of blowing snow and sublimation over Antarctica to better understand the fraction of total SMB.
- Quantify blowing snow over ice sheets with observations or remote sensing measurements. Focus on the ice sheet/sea ice transition to quantify the transfer of snow from land ice to sea ice. Determine blowing snow transport distance and sublimation processes in coastal (wet) and inland (dry) areas.
- Validate and improve blowing snow models over sea ice using in-situ and/or remote sensing observations.

6) How do feedbacks associated with changes in snow cover effect feedbacks in climate models and the atmosphere, specifically albedo and water vapor? What are the impacts of aerosols, rising temperatures, precipitation and cloud cover on surface mass balance and snow on sea ice in the future?

Importance: The albedo feedback is accelerating, especially in the Arctic. Changes in albedo determine the surface radiative balance for the earth. Small changes in snow/ice albedo have a large effect on global temperature. Warming temperatures over the Polar Regions will change the precipitation and cloud cover creating another feedback for further warming. Aerosols, precipitation and cloud cover all effect polar albedo.

- Long term albedo data is needed to determine trends. Legacy dataset, such as the AVHRR data, should be further investigated to determine albedo.
- Improvement and implementation of more sophisticated snow and ice radiative transfer schemes within Regional and Global Climate Models to better simulate albedo-atmosphere feedbacks and reduce uncertainty in future projections
- Establish long term records of clouds in the Polar Regions and assess trends.
- Conduct process studies on the metamorphism of grain size (and other properties) on wet snow.
- Better understand the effects of aerosols from microscale (nucleation in clouds) to macroscale (distribution over ice sheet/sea ice). Anthropogenic aerosols have different effects over the northern and southern hemispheres so both Polar Regions require research.
- Differentiate ice versus water in clouds over ice sheets and sea ice.
- Improve snow and ice radiative transfer schemes within Regional and Global Climate Models to better simulate albedo-atmosphere feedbacks and reduce uncertainty in future projections.
- Continue to validate and improve albedo retrievals from remote sensing methods. Utilize surface or airborne instruments at multiple spectral bands in the Visible and IR wavelengths. Albedo measurements over both the ice sheets and sea ice should be taken multiple times during the melt season and measuring both direct and diffuse radiation. Over the ice sheets establish a transect of surface albedo data over a range of elevations, beyond that provided by the dispersed AWS stations.

7) How will changes in snow depth, and snow properties, on sea ice interact with changes in sea ice conditions to affect the hear flux, surface energy balance and mass balance of the ice? What are the impacts of blowing snow for snow depth on sea ice including both snow loading from land ice and snow loss into the ocean?

Importance: Snow depth, and snow properties, on sea ice determines the heat flux between the ocean, sea ice, and atmosphere. Snow depth on sea ice must be known to accurately determine sea ice thickness from altimetry data. Little is currently known about precipitation over the Southern Ocean.

- Need spatially and temporally consistent surface observations of temperatures, sea ice thickness, and snow depth on sea ice over the Arctic to compare with remote sensing and modeling results. The snow depth climatology needs to be updated for sea ice in the Arctic due to the current accelerated warming, precipitation changes, and loss of multi-year sea ice.
- Quantify blowing snow over sea ice with remote sensing and/or in-situ measurements. Focus on obtaining a maximum rate of snow flux between the ice sheet/sea ice boundary and the sea ice/ocean boundary including loss of snow blown into leads. Determine blowing snow transport distance and sublimation processes over sea ice.
- Inter-compare accumulation data from reanalysis and regional atmospheric models and compare reanalysis data and regional atmospheric model data to in-situ and remote sensing measurements. The models should be run over domains including both the ice sheets and sea ice.
- Conduct routine measurements of precipitation/surface moisture flux over oceans to improve reanalysis data sets.
- Run and assess regional climate models with existing blowing snow models over a domain including both the ice sheet and sea ice.

8) What are the impacts of melt ponds on sea ice?

Importance: Melt ponds change sea ice albedo and contribute to the melting and breakup of sea ice.

- Parameterize water processes in sea ice models specifically the treatment of slush, melt ponds, and flooding.
- Improve parameterization of albedo in sea ice models especially during seasonal transition of seasons from freezing to thawing and with albedo changes due to aerosols.
- Determine the relationship between sea ice melt pond areal coverage and snow accumulation to assess the impact of snow on summer surface albedo.
- Obtain higher resolution reflectance measurements for pond distribution on weekly time scales.